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A Contrastive Study on Dynamic Evolution of Users' Relationship Network in Online Health Community based on Stochastic Actor-oriented Model

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Abstract: Online health community can break the limitations of time and space to provide medical and health information for users, meanwhile can promote the formation and evolution of friendships between users. This paper takes the largest diabetes community in China - SweetHome as the research, and uses the dynamic social network analysis, which is based on stochastic actor-oriented models, to study the impact of individual attributes and network structure on the evolution of users' friendships. It is found that in sub-forums that highly relate to diabetes, basic user attributes such as gender, age, and disease type have significant impacts on the formation of relationships, while in sub-forum of sharing and accompanying, the detailed attributes such as the number of friends, online time, bonus points have a significant impact on the formation of relationships. However, transitive triads have no significant influences on the formation of friends.

Keywords: social network, online health community, friends network, dynamic evolution, stochastic actor-oriented model

1 INTRODUCTION

With the application of Internet technology in the medical industry, online health community gradually appears with the support of health 2.0 technology^[1]. Online health community is the refinement of the online community in the field of health services. In the online health community, users can communicate with others, share medical and health information, participate in forums and other activities to know other users in the community and form friend relationships by adding friends^[2], showing a “weak tie” social relationship. Previous researches mainly focus on the communication relationship, not paying much attention to the friends relationship. However, making friends is a very important part of people's life^[3] as friends can provide information support and emotional support for individuals to help them treat their illness. In the online health community, friends can provide information support and emotional support for others. It is different from the real life that the relationships between users in the online health community are not based on the social relationship in the real world. The previous research shows that the formation of relationships is mainly affected by two factors: user preference and contact opportunity^[4]. With the support of social network technology, online health community facilitates the contact and mutual understanding between users and provides favorable conditions for the formation of the relationships between users^[5]. Users can participate in the same interest topic groups to establish links, and form a friend relationship by adding friends. In addition, the behavior of users in online health community is also very important to the formation of the relationships between friends^[6]. Based on the SweetHome community, this paper selects several sub-forums to study the factors affecting the formation and evolution of user friendship in online health community.

Social network analysis is a great tool to study the influence factors of social relations evolution. Social network is a social structure composed of many network nodes and their relationships, and it's always changing^[7]. The traditional social network analysis method can explain the static network, which explains the status of the relationship network to some extent, but cannot explain the evolution of a relationship network. In the evolution process of friend relationship network, there are new relationships established and some relationships eliminated, which changes the topology of the friendship network. The factors that affect the change of the relationships may be the network structure of the actor, or the actor's personal attributes or

behavior characteristics^[8]. In order to express the dynamic change process of the friend network, and analyze the influence factors of the evolution process according to the diachronic data, this paper uses the dynamic analysis method of social network to analyze multi-periods of the network data. We apply stochastic actor-oriented model which adds the network structure attributes and user attributes into the analytic model and use SIENA (Simulation Investigation for Empirical Network Analysis), a social network dynamic analysis tool, to estimate the parameter based on the actual observed data^[9].

2 THEORETICAL FOUNDATION AND RESEARCH HYPOTHESES

2.1 Homogeneity

2.1.1 Demographic attributes

Homogeneity theory holds that social relations are easier to establish between individuals with similar or identical attributes^[10]. Demographic attributes (such as gender and age) are usually considered to be factors influencing the establishment of social networks^[11]. The research of Shrum shows that there is a significant gender homogeneity phenomenon in the user's friend relationship network, that is, the possibility that people with the same gender become friends is higher^[12]. Durant and other researchers have conducted a study of the online cancer community and found that the duration of maintaining relationships between patients of the same gender was more lasting than that of the opposite gender^[13]. In the real life, the relationships between friends are more likely to be established among people with similar age. Therefore, this paper has the following hypotheses based on the theory of homogeneity:

H1a: The gender of online health community users has a significant impact on the formation of their friend relationships.

H1b: Users with the same gender are more likely to become friends in online health community.

H2a: The age of online health community users has a significant impact on the formation of their friend relationships.

H2b: Users with similar age are more likely to become friends in online health community.

2.1.2 Disease type similarity

The users aim to get health information about related diseases or related experience to obtain social support when they participate in community activities and establish relationships through the online health community^[14]. According to social comparison theory, users can enhance their self-concept and gain self-confidence by comparing with other people in social networks^[15]. Compared with other types of social networks, disease types and illness severity of patient are important in the establishment of the relationships between friends in the online health community^[16]. Two patients with similar health status are able to understand each other better, then they can share the healing process and gain mutual trust^[17]. Therefore, this paper puts forward the following hypothesis:

H3: The membership type of online health community users has a significant impact on the formation of their friend relationships, two users of the same membership type (disease type) are more likely to become friends.

2.2 Activity

There are many different metrics for user's activity in online communities. For example, the theme numbers of users participated in online communities, the number of users' logs and photos in Facebook or Twitter, all of these can be a measure standard of user's activity. Shriver and Nair have found that user's activity has significant positive impacts on the establishment of a friend relationship, active users would receive more attention^[18]. In the online health community, users can increase their bonus points through signing in, posting, replying and other actions. To a certain extent the bonus points reflect the user's activity. Therefore, we regard the user's

bonus points as a measure of activity, and put forward the following hypothesis:

H4: The bonus points of users in the online health community have a significant positive impact on the formation of their friend relationships, people prefer to be friends with other users who have higher bonus points.

2.3 Number of friends

The number of friends reflects the size of user's friendship network. In the online health community, the friendship network is undirected, and users establish friend edges by adding new friends. The formation of a friend relationship in this community is based on the fact that a user sends a request to other users and the request is to be accepted. Shriver's research shows that the number of friends has a significant positive impact on the formation of the relationships between friends.^[18] At the same time, Mayhew and Levinger argued that the time people devoted to building or maintaining a relationship is limited^[19]. People are enthusiastic for something in the early days because of freshness or some purpose, but with their goals gradually achieved, the enthusiasm gradually declines^[18]. Therefore, this paper considers that people prefer to make friends with users who have more friends; and when the number of friends reaches a certain number, the user's enthusiasm for establishing friend relationships will decline. The following hypothesis is presented:

H5: The number of friends of users in the online health community has an influence of inverted U type on the formation of their friend relationships. It can promote the formation of friend relationship edges when users have more friends. But when the friend number reaches a certain number, the influence becomes negative.

2.4 Online time

Online time is the cumulative total time when users log in online health community, reflecting the time users spent on the online community. Tang and Cao found that online time has a positive impact on the formation of college students' friends network^[20]. Research shows that it promotes the formation of the relationships between friends when two users are online at the same time: the users' online activities (posting and replying) are easier to be observed by other users who are online at the same time, and they are more likely to be friends^[18]. We believe that the longer time the users are online, the greater probability of online users to be observed by other users, and the interaction duration with other users will be longer. It is more likely to form a friend relationship among people who have long online time. The following hypothesis is presented:

H6: The online time of users spent on the online health community has a significant positive impact on the formation of their friend relationships, and people prefer to be friends with users whose online time is longer.

2.5 Network structure effects

The formation of social network is a dynamic and complex process. Besides the basic attributes of individuals and the impact of randomness, it is also influenced by the network structure effects^[21], such as reciprocity, network equilibrium, transitive triads and so on. The transitive triads theory originates from experiential judgments in real life: people are more likely to build friendships with friends' friends. The transitive triads theory has been widely used in the study of social networks, the main reasons behind the theory can be summarized as trust, motivation and opportunity^[22]. In undirected networks, the transitive triads are equivalent to the relation transmission, which can be used to study the tendency of network evolution^[23]. It is generally believed that if A and B are friends, B and C are friends, then A and C are more likely to form a friend relationship. Because the premise of building a friend relationship is that two people have the opportunity to "meet" each other^[24]. The presence of B not only increases the opportunity that A "meet" C greatly, but also reduces distrust between A and C by trust transitivity^[25]. Kossinets found that the more common friends of two nodes, the more likely they could establish connections^[26]. In online health community users can access the user's homepage to obtain the user's friends list. So if the user A and B are friends, B and C are friends, then through the intermediary role of B, A and C can quickly establish contact. Thus, the following hypothesis is

presented:

H7: The transitive triads have a significant positive impact on the formation of users' friend relationships in the online health community, and people prefer to be friends with their friends' friends.

3 DATA AND RESEARCH METHODS

3.1 Data

In order to explore the factors that influence user's relationship network evolution in online health community, this paper takes the biggest Chinese diabetes community--- SweetHome (<http://bbs.tnbnz.com/>) as research object. We collect three phases of friendship networks from December 2015 to April 2016. The user attributes include gender, age, membership type, bonus points, the number of friends and online time. For the reason that SIENA works better for the network which owns 10-1000 nodes, this paper chooses four sub-forums of SweetHome community as the research object, which are "juvenile diabetes", "new user promotion", "diets and sports", "prediabetic state" sub-forums. After sweeping out the users who are not the patients, every sub-forum contains 500 users. The user attributes are shown in Table 1:

Table 1. Variable descriptions and summary statistics

Variable	Variable descriptions	Minimum	Maximum	Mean	Std. Dev.
Gender	1=Male, 2=Female	1	2	1.43	0.496
Age	Patient's age	12	78	36.16	14.440
Membership Type	1=type 1 diabetes, 2=type 2 diabetes, 3=other type diabetes	1	3	1.64	0.556
Bonus Point	User's participation activity in the community	0	99320	3395.28	6664.634
Friend Num	Number of user's friends in the community	2	475	19.73	33.289
Online Time	Number of user's online time in the community	0	26970	872.88	1900.228

N=2000.

Table 1 is the descriptive statistics. Male users accounted for 56.8% of the community, while female accounted for 43.2%. The average age of the users is 36. For the part of the disease type, people with type 1 diabetes accounted for 41.1%, people with type 2 diabetes accounted for 55.1%, people with other type diabetes accounted for 3.8%. As for the community involvement, different users differ a lot. User bonus points rank from 0 to 99320, while online time ranks from 0 to 26970 hours. For the part of the number of friends, users own the number of friends from 2 to 475, the average number is 20. Because of the large variance of the bonus points, the number of friends and online time, this paper takes their logarithms for data analysis.

Table 2. The basic information of friends network of “diets and sports” sub-forum

Phase	Number of nodes	Number of edges	Number of newly increased edges
Phase one	500	1795	-
Phase two	500	1825	30
Phase three	500	1865	40

As shown in Table 2, the numbers of edges of three phases of the friendship networks of “diets and sports” sub-forum are 1795, 1825 and 1865. The number of edges of the friends' relationship network is increasing steadily. And there are no edges decreased in the evolution process of the friends' relationship network which indicates that the relationships between users are stable. We used Gephi, a software for social network analysis,

to visualize the three phases of networks. The topology graphs of networks are showed in Figure 1. It can be seen that the friends' network is moving and changing constantly.

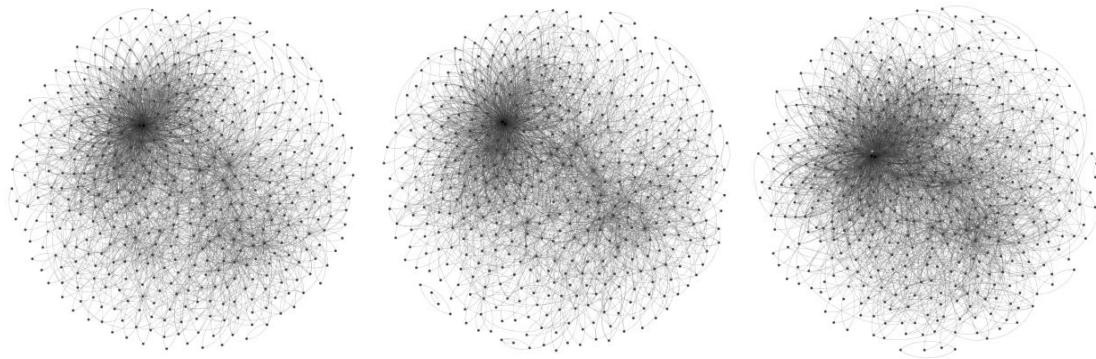


Figure 1. The topology graphs of networks of “diets and sports” sub-forum

3.2 Research methods

Traditional social network analysis method can analyze static network, but cannot explain the diachronic data^[9]. In order to express the dynamic change of the network based on the diachronic observation data, the dynamic analysis method of social network is needed to explore the factors that influence the dynamic change of the network. Based on the stochastic actor model, this paper uses a social network dynamic analysis tool SIENA for dynamic network analysis.

SIENA is mainly based on stochastic actor-oriented models to analyze the dynamic change of network^[27]. The model considers that the formation and evolution of the network are determined by the action of nodes in the network, and each node decides to establish or disconnect contacts with other nodes by controlling its out-degree. Each node tries to optimize its social structure in the process of network evolution^[7], which eventually makes the change of the whole network. The model takes the network change as a dependent variable, and takes node attributes, network structure and other random variables as independent variables to cause nodes change the link. SIENA uses the computer to randomly produce Markov process in the actual operation process, and combines the diachronic longitudinal data of social network to simulate the evolution of social network structure. This method uses Monte Carlo simulation method to estimate the Markov model parameters, each parameter θ to be estimated in the model will be compared with statistical data obtained from actual observation or simulation. Retry the parameters and if the D-value is getting smaller, means the parameter estimation is in a convergence, then take the convergent parameter as the estimated parameters of this simulation process^[8]. Users can determine the significance of the parameters by t-statistics. The evolution of online health community friend relationship network is a Markov process that continuously changes with time. The estimated parameters of the model can be inferred from the observed data, so as to verify the factors affecting the evolution of the friend network.

In this paper, SIENA is implemented through the RSiena package of R language, which can read data, set effects, complete the model parameter estimates and output analysis results easily. The attribute effects used in this paper mainly include the same effect and the similarity effect, which reflect the role of homogeneity in the formation and evolution of interactive networks. If the estimated same effect of an attribute is positive, it is shown that the two nodes with the same attribute value are more likely to form an edge, such as the same gender. If the estimated similarity effect of an attribute is positive, it is shown that the two nodes with the similar attribute value are more likely to form an edge. SINEA is well suited to test our hypotheses that it can estimate all possible factors simultaneously.

4 RESULTS

The results of parameter estimation and significance analysis are shown in Table 3. Most of the parameters estimated in the model have good convergences, and individual parameters of different sub-forums vary a lot, which is related to the characteristics of the sub-forums. The t-statistic indicates the level of convergence of parameters. If the absolute value of t-statistic value is less than 0.1, it is considered that the parameter converges, and the obtained parameter estimation results are valid^[5].

Table 3. Stochastic actor-oriented models estimation results

Variable	Parameter estimation (t-statistic)			
	Juvenile diabetes	Prediabetic state	New user promotion	Diets and sports
Rate parameter period 1	0.0561 (--)	0.0986 (--)	0.0428 (--)	0.1755 (--)
Rate parameter period 2	0.3085 (--)	0.5061 (--)	0.1106 (--)	0.8038 (--)
Degree (density)	-2.6771 (-0.0322)	-2.6040 (0.0538)	-2.2032 (-0.0430)	-2.4547 (-0.0318)
Transitive triads	0.0829 (-0.1324)	0.0607 (-0.3019)	0.0017 (-0.2089)	0.0101 (-0.2580)
Gender	-0.0390 (-0.0279)	0.0958 (0.0071)	0.0974 (-0.0226)	0.1066 (0.0647)
Same gender	-0.0620 (-0.0488)	-0.1729 (-0.0235)	-0.4800 (-0.0416)	-0.1666 (-0.1202)
Age	-0.0069 (0.1605)	-0.0009 (-0.0389)	0.0132 (-0.1108)	0.0029 (-0.0291)
Age similarity	-0.3296 (-0.0036)	-0.1202 (-0.0999)	1.6366 (0.0087)	0.1235 (0.0322)
Same membershipType	0.4500 (-0.1036)	0.3724 (0.0624)	0.4787 (0.0124)	0.2824 (0.1771)
FriendNum	0.5197 (-0.1336)	0.5940 (-0.1601)	0.8169 (-0.0273)	0.5966 (-0.0763)
FriendNum squared	-0.1112 (-0.0826)	-0.0148 (-0.1768)	-0.0174 (-0.0480)	-0.0179 (-0.1431)
OnlineTime	0.0158 (0.1645)	0.0809 (-0.1376)	0.2483 (-0.0579)	0.0538 (-0.0819)
BonusPoint	0.1221 (0.1193)	0.0187 (-0.1466)	-0.0708 (-0.0776)	0.0006 (-0.0632)

Note: t-statistics = (observed value - sample average) / standard error, low parameter statistics mean that parameters are convergent in the estimation process.

The rate parameter reflects the evolution speed of different stages of network. *Rate parameter period 1* and *rate parameter period 2* correspond to the change of the friend edges from phase one to phase two and from phase two to phase three.

Because the four sub-forums studied in this paper have different characteristics, the factors that affect users to establish a friendship edge are different in different sub-forums, the following are the detailed analyses of each sub-forum.

In the juvenile diabetes sub-forum, we find that *gender* has a significant impact on the formation of the friendship edges ($|t| < 0.1$) but people are more likely to establish a friend relationship with users of different gender ($|t| < 0.1$, $\beta = -0.0620$). The results indicate that man are more likely to make friends with others. Men and women can be complementary with each other in ways of thinking perspectives and attitudes, thus promoting the establishment of connections. Besides, *age* has no significant influences on the formation of the friendship edges ($|t| > 0.1$). This is due to the majority of users in the sub-forum is child's parents or family members, users do not require the age of each other. This sub-forum is closely related to diabetes, the main purpose of users in this sub-forum is to obtain information related to juvenile diabetes to cope with the timely treatment with high pertinence and urgency. A small number of users encourage and comfort each other, seeking for emotional support. Therefore, the users' detailed attributes (the membership type, bonus points, the number of friends and online time) do not affect the formation of friendship in this community significantly.

In the prediabetic state sub-forum, *gender* also has a significant impact on the formation of the friendship edges and people are more likely to establish a friend relationship with users of different gender. *Age* has a significant impact on the formation of the friendship edges ($|t| < 0.1$) but the greater the age difference is, the

more likely users to be friends with each other ($|t| < 0.1$, $\beta = -0.1202$). This is because the early diabetic patients are mostly young people, and young people lack experience. They are more eager to seek advice from older people with diabetes treatment experience to alleviate the physical and psychological pressure. In addition, this sub-forum is close related to diabetes, so users are very concerned about membership type (disease type) when making friends, and are eager to receive help and encouragement from users with the same type of disease. So users with the same disease type are more likely to be friends ($|t| < 0.1$, $\beta = 0.3724$). Most users in this sub-forum have just got diabetes. Compared to long-term patients, prediabetic state users hope to get more information and do not care about the detailed attributes of other users, so bonus points, the number of friends and online time have not significant effects on user's behavior in this community.

In the new user promotion sub-forum, the impact of *gender* on the formation of the user friendship edges is the same with the above two sub-forums. The influence of *age* on the formation of the friendship edges is not significant ($|t| > 0.1$). Most users in this sub-forum have just registered, and their main purpose is to be familiar with the community and to make a lot of friends, so they do not pay much attention to other users' age. Besides, users of the same disease type are more likely to be friends ($|t| < 0.1$, $\beta = 0.4787$). Since this sub-forum is a sharing and chatting sub-forum, users want to accompany with others. Users who have longer online time have more opportunities to interact with others, and are more easily to establish a friend relationship ($|t| < 0.1$, $\beta = 0.2483$). In addition, it shows that users who are less active are more likely to establish relationships with others ($|t| < 0.1$, $\beta = -0.0708$). This is because they are almost new registered users in this sub-forum, and they are more eager to make friends with people in similar condition. *FriendNum* has positive effects on the formation of friendship edge ($|t| < 0.1$, $\beta = 0.8169$), while the influence of *friendNum squared* is not significant ($|t| < 0.1$, $\beta = -0.0174$), which indicates that it can promote the formation of the friend relationship edges when users have more friends, but when the friend number reaches a certain number, the influence becomes negative.

In the diets and sports sub-forum, *gender* has a significant impact on the formation of the friendship edges ($|t| < 0.1$). However, gender difference has no significant influences on it ($|t| > 0.1$). This is related to the characteristics of the healthy lifestyle of users in this sub-forum, and there are no significant differences of the eating and exercise patterns between different gender users. *Age* has a significant influence on the formation of the friendship edges ($|t| < 0.1$), and the older patients are more likely to establish relationships with others ($\beta = 0.0029$). This is because older users have more leisure time and they pay more attention to health and exercise, hoping to create a healthy life with other similar users. The results indicate that users with similar age are more likely to become friends ($|t| < 0.1$, $\beta = 0.1235$), which may because users with similar age have similar experience, hobbies and more likely to reach an agreement on the ideas and actions. However, *same membershipType* has no significant impacts on the user's friendship formation ($|t| > 0.1$), as the ways of having a healthy life are common for different types of diabetics. And in this sub-forum, the longer the user's online time is, the more likely they establish relationships with others ($|t| < 0.1$, $\beta = 0.0538$). It is because this sub-forum is a sharing type sub-forum, the main function is to provide emotional support and companionship for patients. The longer the online time users have, the more likely they attract others and become friends. Similarly, in this sub-forum, users are more willing to be friends with active users ($|t| < 0.1$, $\beta = 0.0006$). *FriendNum* has positive effects on the formation of friendship edge ($|t| < 0.1$, $\beta = 0.5966$), while the influence of *friendNum squared* is not significant ($|t| > 0.1$), which indicates that users are more likely to be friend with the one who has more friends. However, the average users' friend number is 19 in this sub-forum, not high enough to bring trouble to users, the users are in the stage of being willing to make friends.

Network structure attribute (*transitive triads*). The absolute values of t-statistics of *transitive triads* of all sub-forums are greater than 0.1, which indicates that transitive triads have no significant influences on the formation of the user friendship edges, and H7 is not supported. This may because the main purpose of users

participated in online health community is seeking for health information. The motivation of making friends in online health community is weaker compared to other social networks. Users in online health community are almost strangers. They make friends just for the purpose of getting knowledge and information about health timely. They know little about the friend's personal life, so they have less intention to establish a contact with a friend's friend.

Users have different motivations and requirements about making friends in different types sub-forums with different functions. Table 4 summarizes the results of all the hypotheses of the sub-forums above.

Table 4. Summary of results

Dimension	Hypothesis	Result			
		Juvenile diabetes	Prediabetic state	New user promotion	Diets and sports
Demographic attributes	H1a	Supported	Supported	Supported	Supported
	H1b	Not supported	Not supported	Not supported	Not supported
	H2a	Not supported	Supported	Not supported	Supported
	H2b	Not supported	Not supported	Not supported	Supported
Disease type similarity	H3	Not supported	Supported	Supported	Not supported
Activity	H4	Not supported	Not supported	Supported	Supported
Number of friends	H5	Not supported	Not supported	Supported	Not supported
Online time	H6	Not supported	Not supported	Supported	Supported
Network structure effects	H7	Not supported	Not supported	Not supported	Not supported

The hypotheses we put forward in this paper are mostly based on the cognitive experience of offline community or ordinary online community. Table 5 shows that many hypotheses are not supported in online health community. It indicates that there are huge difference of friendship formation between online health community and ordinary online community. First of all, “juvenile diabetes” and “prediabetic state” are two sub-forums that are closely related to diabetes. In these two sub-forums, users yearn for useful information about the treatment of their disease, and they attach more importance to information accuracy. A small number of users are concerned about other users' basic attributes (age, gender, and membership type). However, users basically do not care about the detailed attributes (activity, number of friends and online time) of users who provide information. In contrast, “new user promotion” and “diets and sports” are more similar to ordinary company community, in which users can chat and make friends, share interesting stories or attitudes about diabetes. Therefore, in these kind of company sub-forums, users pay attention to other users' basic attributes and detailed attributes at the same time, and care the similarity of other users' illness or interest, so as to decide whether to become friends with them.

5 CONCLUSION

This paper chooses the largest diabetes community - SweetHome as the research object, and uses dynamic analysis method of social network based on stochastic actor-oriented models to study the influence of the individual attributes and attributes of network structure on the evolution of users' friendships in online health community. The results show that in sub-forums with a high correlation with diabetes, basic user attributes such as gender, age, disease type have significant influences on the formation of the relationships between friends. In the sub-forum of sharing and accompanying, the detailed attributes of users such as the number of friends, online time, bonus points have significant impacts on the formation of the relationships. The influences of these factors are related to the sub-forum characteristics. However, the network structure attribute (transitive triads) has no significant influence on the formation of friends in these online health communities.

In this paper, we study the main factors that affect the formation of user friend relationships in the online health community that patients interact with others. In online health communities, medical experts and patients, family members belong to the same level of users, with equal rights to broadcast information, express feelings, seek help and discuss. Compared with the aptotic cause of the formation of users' friend relationships in online health community that patients interact with doctors (the patient seeks medical help from doctors), the formation of user friendships in patient-to-patient health community are more complex and diverse. When patients become friends, the exchange of illness condition and companionship become more convenient and frequent, which is conducive to the dissemination of information and rehabilitation of patients. This is correspond to the service purpose of online health platform. Platform managers can take certain incentives to attract users to increase the length of online time to encourage users to participate in discussions and increase the probability of establishing a friend relationship between users. Besides, in this way they can enhance community cohesion and activity, improve the sense of trust between users on the platform, promote the healthy and rapid development of online health platform, and make contribution to the popularization of online medical industry.

However, this paper does not further explore the impact of users' posting content on the evolution of the network, which makes the research not comprehensive enough. The text content is also an important factor affecting user's perception and evaluation, which may affect the establishment of edges with other users. Therefore, future research will consider the impact of text content and the roles of users on the formation of the relationships based on the text content shared by users.

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